Investigation of Near-Axial Interference Effects in Long Range Acoustic Propagation in the Ocean

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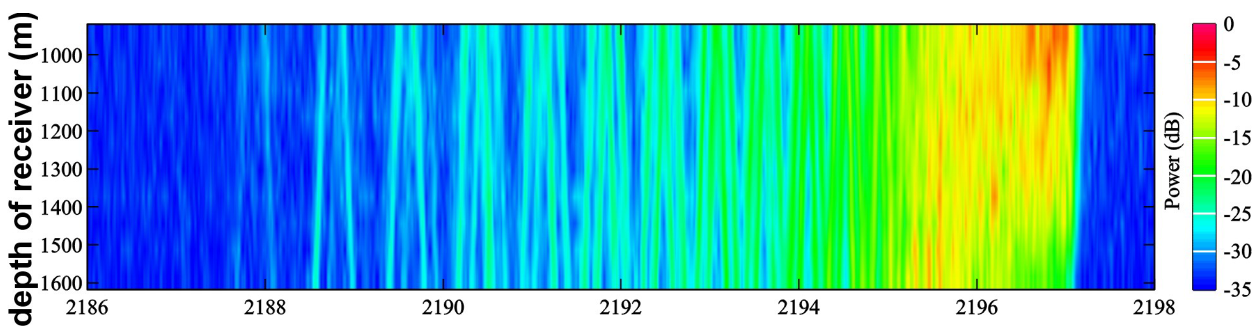
LONG-TERM GOALS

The long-term goal of this effort is to provide an improved way of interpreting the experimentally observed time-of-arrival patterns in long-range, low-frequency propagation in the deep ocean.

OBJECTIVES

In many long-range propagation studies the source and receiver are placed close to the depth of the waveguide (SOFAR) axis to minimize the interaction of the acoustic field with the ocean's surface and bottom. The most pronounced characteristics of the time-of-arrival patterns for these experiments are early geometric-like arrivals followed by a crescendo of energy that propagates along the axis. In the following figure these characteristics are clearly shown for a time-of-arrival pattern measured during the AET experiment. This figure was adapted (with permission) from one published in Ref. (1).



All applications to use the geometrical acoustics to describe the propagation of energy along the waveguide axis are failed. It could be the failure results from the existance of cusp caustics repeatedly along the axis. The following figure illustrates this pattern of caustics. It is a ray tracing for a source on the axis (and for relatively short ranges). In neighborhoods of cusp caustics a very complicated interference pattern is observed. The neighborhoods of interference grow with range and at extrimely long ranges they even can overlap. Therefore a study of propagation when the geometrical solution is characterized by a multitude of cusp caustics should include an investigation of the interference of near-axial waves.

The overall goal of the research is to provide a better understanding of the interference effects that are present for wave propagation in a ducted waveguide when the source and receiver are located near or

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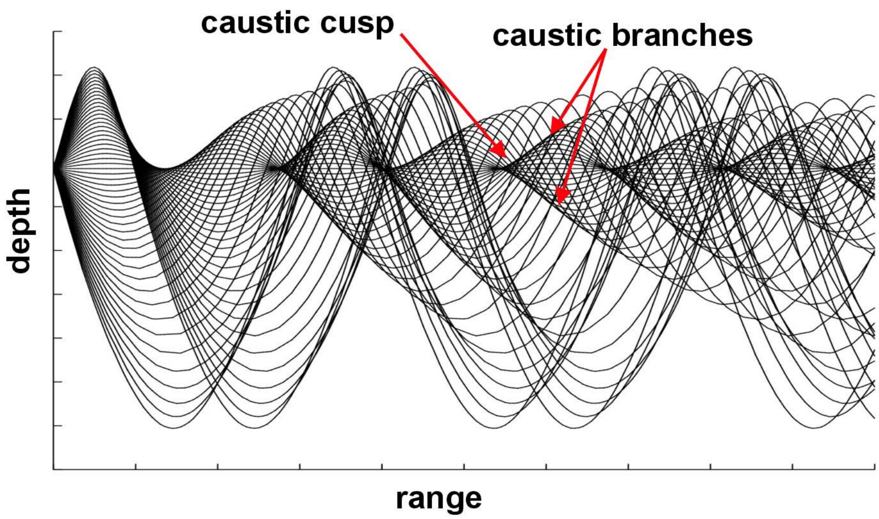
on the axis of the duct. The primary application of this work will be the interpretation of time-of-arrival patterns observed in long-range acoustic propagation experiments in the ocean.



APPROACH

To study the relationship between the crescendo and the cusp caustics structure, a high-frequency asymptotic representation of the field is needed that does not have caustic singularities. The Maslov's representation (Ref.(2)) of the wave field is free of singularities at the location of caustics. However it can have singularities at other locations – the location of so called "pseudocaustics". These singularities could complicate interpretation of results. Klauder's coherent transform representation (Ref. (3)) is singularity free and is worth considering because it admits a path integral representation suggesting useful computational and analytic tools. There is another asymptotic representation, however, which is free from singularities. It was designed specially for the study of near-axial propagation in a ducted waveguide. This is the representation developed by Buldyrev and coworkers (Refs. (4)-(6)). Buldyrev showed that the interference of the wave fields that corresponds to near-axial rays, and is associated with the cusped caustics, leads to a coherent structure that propagates along the axis like a wave. In regions removed from caustics this structure, called the "axial wave" reduces to the simple wave associated with the ray path that propagates along the axis of the waveguide.

Buldyrev's work on the axial wave was done before the long-range experiments took place and with the purpose of obtaining a global description of propagation in the presence of cusped caustics. The integral representation for the axial wave in the frequency domain was obtained only for a symmetric range-independent waveguide when both the source and observation point were on the axis.

The goal of the first year's effort on the project was to obtain the integral representation for the axial wave in the frequency and time domains for an arbitrary range-independent waveguide when the receiver is placed close to the depth of the waveguide axis.

This work represents a collaboration between N.S. Grigorieva and G.M. Fridman at the St. Petersburg State Marine Technical University and D.R. Palmer at NOAA/AOML in Miami. Professor Grigorieva is responsible for summarizing and interpreting the Russian work relating to the project, for analytic analysis, and overseeing the work by Professor Fridman who is responsible for numerical calculations. Dr. Palmer is responsible for interpreting the relevant long-range propagation experiments.

WORK COMPLETED

The integral representation of the axial wave was obtained in the form of a linear superposition of the solutions of the homogeneous Helmholtz equation which are concentrated near the waveguide axis. The weight function was found from the principle of locality using the exact solution of the reference point source problem where the index of refraction squared is parabolic.

1. In the reference problem the exact solution was transformed in such a way to extract ray summands, corresponding to rays radiated from the source at angles less than a certain angle, and the axial wave.
2. The solutions were obtained for the homogeneous Helmholtz equation concentrated near the waveguide axis that decrease exponentially outside a strip containing the axis.
3. The integral representation of the axial wave in an arbitrary range-independent ocean was obtained when the receiver is located near the waveguide axis.
4. Through numerical simulation a study of the dependence of the axial wave on frequency, range, and sound speed characteristics was carried out.
5. A draft summary of the experimental work on long-range, low-frequency propagation in the ocean was completed.
6. The representation for the axial wave in the time domain was obtained and its intensity in a three-dimensional, range-independent medium was computed.

For the fourth quarter of the first year (18 September, 2003 – 17 December, 2003), the major tasks are:

1. Study of the axial wave in the time domain will be completed. In particular, the dependence of the axial wave on the characteristics of the sound speed will be thoroughly studied.
2. A summary of Buldyrev and co-workers research relating to the axial wave will be completed.

PERSONNEL EXCHANGES AND TRAVEL COMPLETED

Table 1. Summary of personnel exchanges and travel conducted under this NICOP.

Name	Home Institution	Institution/ Location Visited	Scientific/ Technical Purpose of Visit	Dates (mm/dd/yy)
Grigorieva N.	SMTU	Honolulu, Hawaii	Participation in the Sixth Int. Conf. on Theor. and Comp. Acoustics	08/08/03 – 08/17/03
Grigorieva N FridmanG.	SMTU	NOAA/AOML, Miami	Project workshop	09/13/03 – 09/25/03

RESULTS

1. We concluded that in a range-independent ocean the integral representation of the axial wave can be constructed from the solutions of the homogeneous Helmholtz equation concentrated near the axis of a waveguide as their liner superposition. It follows from the comparison of this integral representation with the integral representation obtained from the exact solution of the point source problem.

2. We concluded that the obtained form of integral representation of the axial wave in a range-independent ocean allows to propose the formula for the axial wave in a range-dependent ocean where this wave again can be constructed with the use of the solutions of the homogeneous Helmholtz equation concentrated near the waveguide axis.

IMPACT/APPLICATIONS

This effort represents a new opportunity for collaboration between U.S. acousticians and Russian specialists in wave propagation. The so-called St. Petersburg school of diffraction and wave propagation, associated primarily with the names of Profs. Babich, Buldyrev, and Buslaev, and even earlier Prof. Fock, has developed asymptotic techniques that have had worldwide application to a host of applied problems. In addition, the researchers in St. Petersburg associated with this school did extensive work in underwater acoustics during the 1980's and earlier. Unfortunately no collaboration existed between U.S. acousticians and members of this St. Petersburg school. The benefits that can come from such a collaboration are great. The present work represents a unique opportunity to apply theoretical research done by this school to pragmatic problems in underwater acoustics. For the first time Russian theoretical research not generally known in the U.S. is used to help interpret U.S. long-range underwater acoustics experiments. The benefits are not one-sided. If there is a weakness in the St. Petersburg school, it is that it is somewhat isolated from contact with those who apply its theoretical research. Russian researchers have an opportunity to learn some of the practical aspects of recent, exciting, sound propagation experiments conducted under Navy auspices.

TRANSITIONS

A better understanding of the interference effects in long-range underwater acoustics experiments could not only provide new methods of exploiting these experiments for ocean acoustic remote sensing, including climate and nuclear explosion monitoring, but could also provide a basis for future, unanticipated, applications of low-frequency acoustics. New ocean remote sensing techniques have obvious societal benefit. The techniques to be developed for realistic models of range-dependent ocean and the knowledge to be gained has relavance to other fields including electromagnetic propagation in the atmosphere and wave propagation in elastic media.

RELATED PROJECTS

This work falls within the context of the ONR Ocean Acoustics Program (Code 321OA) S&T Thrust, Long-Range Propagation. It complements the Code 321OA theoretical work having grant numbers N000149710046, N000140110313, N000149810540, N000149810079, N000149810899, N000149710426, and N00014031P20002 and experimental work on long-range propagation having grant number N000149710258.

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